Zoosyst. Evol. 101 (3) 2025, 1309–1324 | DOI 10.3897/zse.101.158479

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Post-2000 milestones in freshwater fish taxonomy: a comprehensive review of newly described species in Türkiye

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Academic editor: Nalani Schnell ♦ **Received** 9 May 2025 ♦ **Accepted** 23 June 2025 ♦ **Published** 30 July 2025

Abstract

The 2000s are the revolutionary decade for the taxonomy of freshwater fishes of Türkiye in terms of the most significant ever rate of increase in species descriptions. Among the approximately 390 freshwater fish species reported from Türkiye, a remarkable 136 have been described since 2000, reflecting an accelerated pace of taxonomic and morphological activity. This surge has been prompted by the influx of new researchers and the widespread adoption of molecular sequencing techniques, currently at the center of taxonomic work since the 2010s. This synthesis gives a complete view of these 136 new species named, examining predominant parameters such as genera, descriptors, contributing countries, and the chronological order of discoveries. The results are presented through visual data, which help illustrate the progress in taxonomic research and the contributions of international collaboration. The study also highlights the rapid development of freshwater biodiversity research in Türkiye and emphasizes the value of using integrated methods and global partnerships to better understand less-studied aquatic species. The bibliometric analysis indicates that a substantial proportion of new species descriptions is ascribed to a limited cohort of prolific researchers, with the majority of contributions made by a core group of the top 10 authors. These discoveries not only augment our comprehension of Türkiye's freshwater fish fauna but also illuminate broader trends influencing taxonomic study in the 21st century.

Key Words

Bibliometric analysis, biodiversity, freshwater fishes, review, systematic ichthyology, taxonomy

Introduction

Located at the intersection of three of the world's 36 biodiversity hotspots – namely the Caucasus, Iran-Anatolia, and Mediterranean Basin – Türkiye hosts a rich and diverse array of species (Kaya 2019; Giannetto and İnnal 2021), with freshwater fishes being no exception (Freyhof et al. 2025). Due to the country's numerous closed basins and independent river systems, a substantial proportion of its freshwater fish fauna is endemic (Giannetto and İnnal 2021). Scientific interest in Türkiye's freshwater ichthyofauna dates back to the 19th century, with one of the earliest significant contributions made by Abbott (1835), who documented trout species (Salmonidae) in streams of northeastern Anatolia. Later, Wallace (1876) published the first global map of zoogeographic regions and highlighted the biodiversity of Anatolia, stating, "... *European Turkey are more woody and luxuriant, but it is perhaps in Asia Minor, on the range of the Taurus, along the shores of the Black Sea, and to the south of the Caucasus range, that this sub-region attains its maximum of luxuriance in vegetation and in animal life.*" During this

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period, foreign researchers visiting Türkiye for various purposes developed an interest in its freshwater biodiversity. They frequently collected fish specimens and transported them to their home countries for further studies (Geldiay and Balık 2007). A major milestone in the documentation of Turkish ichthyofauna came in 1915 with the publication of "Fish and Fisheries in Türkiye", a foundational work authored by Karekin Deveciyan – who later became the director of Istanbul's fish market. His work aimed to provide the first detailed checklist of the country's freshwater fishes (Deveciyan 1926). Although the book does not present a critical revision of previously described species, it stands as the first comprehensive effort to catalog Türkiye's freshwater fish species. Deveciyan's volume remains an invaluable resource, offering both taxonomic and ecological information, as well as insights into distribution and fisheries, thereby bridging scientific exploration with practical knowledge.

Until 1939, most ichthyological studies in Türkiye were conducted by foreign researchers, with a primary focus on the Black Sea Region. A pivotal shift occurred in 1937, when Professor Curt Kosswig began working at the Faculty of Science at Istanbul University. Kosswig played a central role in encouraging students and colleagues to engage in freshwater fish research, laying the groundwork for a national tradition in ichthyology (Gaygusuz et al. 2021). This tradition gained significant momentum between 1940 and 1949. Among the leading figures of this era was Professor Fahire Battalgazi, Türkiye's first woman ichthyologist. At a young age, she described numerous new freshwater fish species, making substantial contributions to the field (Battalgil 1940, 1941, 1942, 1944; Battalgazi 1944). Her pioneering work brought Türkiye's freshwater ichthyofauna to the attention of the international scientific community (Gaygusuz et al. 2021). However, between 1950 and 1970, research activity declined within the country. This gap was largely filled by foreign scientists, who focused on freshwater fishes in Türkiye's neighboring regions, sometimes including data from the Turkish side, especially the Black Sea Region. Notably, Berg (1948, 1949a, 1949b) included Turkish species in his comprehensive three-volume work on the freshwater fishes of Russia and adjacent areas. Likewise, Slastenenko (1956), in his study of the geographical distribution of marine and freshwater fishes in the Black Sea Basin, reported species from near Trabzon – a northeastern province of Türkiye – and the Çoruh River.

By the 1970s, scientific interest in the eastern regions of Türkiye began to grow. Kuru (1971) recorded 32 species and 2 subspecies across seven families in the Kura-Aras, Karasu-Murat, and Çoruh rivers in Eastern Anatolia. Aras (1974) followed with a study on the biological and ecological characteristics of trout (Salmonidae) inhabiting the Çoruh and Aras rivers. Building on this foundation, Kuru (1975) conducted a systematic and zoogeographical study of the Tigris–Euphrates, Kura–Aras, Lake Van, and Central and Eastern Black Sea basins, recording 39 species and 29 subspecies across 13 families. Among the contributions from this period, Kelle's (1978) study of the Tigris River stands out as the most comprehensive, documenting 21 species and 4 subspecies from 18 genera. Collectively, these studies represent the first significant steps toward understanding the ichthyofauna of eastern Türkiye.

Until the early 2000s, freshwater fish research in Türkiye remained limited to scattered local surveys (e.g., Balık 1979, 1985, 1988; Meriç 1980, 1986a, 1986b; Erk'akan 1983, 1984; Özuluğ 1999; Sarı et al. 1999). However, noteworthy among these were the works of Süleyman Balık, who provided baseline data for various regions: Western Anatolia (Balık 1979), Thrace (Balık 1985), and the Mediterranean region (Balık 1988). Since 2006, major advances have been achieved through extensive fieldwork and taxonomic studies led by Davut Turan, Müfit Özuluğ, and Jörg Freyhof, which significantly expanded knowledge of the country's freshwater fish diversity (Turan et al. 2006, 2008, 2010; Özuluğ and Freyhof 2007a, 2007b, 2011). Important contributions have also come from Nina Bogutskaya and Fahrettin Küçük, particularly in the taxonomy of Leuciscids (Bogutskaya et al. 2000, 2006), and from Füsun Erk'akan, who has worked extensively on Nemacheilids (e.g., Erk'akan et al. 2007, 2008; Erk'akan 2012). Additional progress has been made by researchers such as F. Güler Ekmekçi, Semih Engin, and Maurice Kottelat, who have helped resolve taxonomic challenges and described numerous new species (Turan et al. 2006, 2008, 2010, 2012, 2014a).

The first comprehensive molecular study on the freshwater fishes of Türkiye was conducted by Geiger et al. (2014), covering a broad geographic range and highlighting the remarkable diversity of the region. The integration of molecular tools into systematic studies in the 2010s greatly accelerated species discovery. For instance, Anatolian spirling populations were long considered to belong to *Alburnoides bipunctatus* (Geldiay and Balık 2007; Bogutskaya and Coad 2009; Turan et al. 2013), but studies by Davut Turan and colleagues revealed substantial undescribed diversity within the genus *Alburnoides* Jeitteles, 1861, using mitochondrial sequences. As a result, the number of recognized species of *Alburnoides* in Türkiye has grown to 14, including 10 species described since 2013 (Turan et al. 2013, 2014b, 2016, 2017a, 2019a; Kaya 2020). Similarly, the genus *Salmo* Linnaeus, 1758, underwent major revision. Previously grouped under *Salmo trutta macrostigma* or *Salmo trutta caspius*, Anatolian populations have now been shown to include about 20 distinct species, thanks to Turan and colleagues (e.g., Turan et al. 2010, 2012, 2014c, 2017b, 2020, 2021, 2022, 2024c; Küçük et al. 2024). These studies mark key advances in uncovering the hidden diversity of Türkiye's freshwater fish fauna. Moreover, the genus *Pseudophoxinus* stands as a signature element of Anatolia's freshwater fish diversity. In recent years, intensified taxonomic exploration has uncovered substantial variation, raising the documented species total to 22 (e.g., Küçük et al. 2013, 2016; Küçük and Güçlü 2014; Saç et al. 2019a, 2019b).

One of the most significant examples of progress in species delimitation and the resolution of systematic confusion through combined morphological and molecular

approaches is found in studies on the family Nemacheilidae. For many years, the taxonomic status of numerous populations of Nemacheilidae remained unclear due to extensive nomenclatural confusion at both species and genus levels (Erk'akan et al. 2007, 2008), hindering a comprehensive understanding of the diversity within the family. However, after years of intensive research, much of this confusion has been resolved (e.g., Freyhof et al. 2012, 2019, 2022; Esmaeili et al. 2014; Yoğurtçuoğlu et al. 2020, 2022). The description of 40 new species in Türkiye between 2006 and 2024 strongly reflects this progress (e.g., Freyhof et al. 2021; Turan et al. 2019b, 2024a, 2024b; Yoğurtçuoğlu et al. 2021a, 2021b; Kaya et al. 2020, 2021, 2024a, 2024b) (Suppl. material 1). Following a number of taxonomic revisions in recent years, such as those mentioned above, the number of freshwater fishes in Türkiye has become somewhat clearer. Çiçek et al. (2023) reported 427 freshwater fish species from Türkiye. However, this number is likely overestimated. Their list includes several marine or brackish species, such as *Sprattus sprattus* (Linnaeus, 1758) and *Pomatoschistus anatoliae* Engin & Innal, 2017, which do not establish freshwater populations. It also contains species not known from Türkiye, like *Oxynoemacheilus bureschi* (Drensky, 1928) and *Oxynoemacheilus chomanicus* Kamangar, Prokofiev, Ghaderi & Nalbant, 2014, likely due to past misidentifications. Moreover, several taxa listed as valid have recently been synonymized (e.g., *Luciobarbus kottelati* Turan, Ekmekçi, İlhan & Engin, 2008, and *Chondrostoma angorense* Elvira, 1987) (Küçük et al. 2023; Freyhof and Yoğurtçuoğlu 2024).

The aim of this synthesis is to trace the evolution of research on the freshwater fish fauna of Türkiye since 2000 – a period marked by a significant increase in species descriptions. Following two decades of intensive research, it is now anticipated that the rate of new discoveries has begun to decline. Nevertheless, the potential for uncovering previously unknown species remains high, especially among species confined to isolated or restricted habitats such as caves or small, remote, and closed water systems. We predict that future discoveries will likely be unexpected and will require meticulous, localized, and in-depth investigations. A second objective of this review is to conduct a bibliometric analysis of the top ten researchers who have described the greatest number of new freshwater fish species in Türkiye. Through this analysis, we aim to evaluate the contribution of these leading scientists and to assess their impact on the advancement of ichthyological research in the country. Such a bibliometric analysis of key contributors in the field is expected to yield valuable perspectives on research dynamics and productivity trends.

Materials and methods

This review critically examines recent developments in the taxonomy of the freshwater fishes of Türkiye, with special attention to the accuracy of taxonomic checklists, taxonomic changes, the availability of molecular data, and the contributions of different researchers. It focuses on species validity, nomenclatural accuracy, the availability of reference mitochondrial sequences, and the role of contributing researchers. The analytical methods employed in this assessment are detailed below.

Species validity and nomenclature

To ensure accuracy, the validity of the species names reported here was checked using the "Eschmeyer Catalog of Fishes" (Fricke et al. 2025), and their systematic placement follows Freyhof et al. (2025). This ensures that the study reflects the most updated and widely accepted taxonomic standards. All data examined in this review – including cited literature, recorded species, and relevant metadata – are provided as Suppl. material 1. This supplementary file offers readers a transparent and comprehensive overview of the analyzed data, facilitating further exploration and verification. The map included in the study was generated using ESRI Basemaps (2025).

Availability of mitochondrial sequences and DNA barcoding

We focused on the mitochondrial gene encoding Cytochrome c oxidase subunit I (COI), the mitochondrial marker internationally recognized for DNA barcoding in animals (Hebert et al. 2003a, b; Hubert et al. 2008). To retrieve DNA barcode records for freshwater fish species described from Türkiye since 2000, we used the Barcode of Life Data System (BOLD; Ratnasingham and Hebert 2007). The 'Checklist' function in BOLD was employed to identify species with available COI sequences. A dataset was subsequently created in BOLD to assess the effectiveness of DNA barcoding in delineating species boundaries among those described since 2000. The dataset is publicly available at https://doi.org/10.5883/DS-TUR00.

Comparisons were made between the K2P genetic distances (Kimura 1980) within species – as estimated by the maximum K2P distance – and between species using the minimum K2P distance. We also examined the results of the species delimitation algorithm used by BOLD to assign Barcode Index Numbers (BINs; Ratnasingham and Hebert 2013).

Measurement of individual contributions

A bibliometric analysis was conducted using the Web of Science Core Collection database. In this context, the top ten authors who have described the highest number of new fish species in Türkiye were identified. Each author's name was entered individually into the search console using the "Author" field, combined with the "OR" operator. The selected authors were as follows: "TUR-

AN, D.," "FREYHOF, J.," "KAYA, C.," "BAYCELEBI, E.," "GEIGER, F.M.," "OZULUG, M.," "KUCUK, F.," "KOTTELAT, M.," "YOGURTCUOGLU, B.," and "BEKTAS, Y." The search was refined using the following filters: publication year (2000 onwards), country/region (TÜRKİYE and TURKEY), Web of Science indexes (SCI-EXPANDED and ESCI), and document type (article). The bibliometric analysis was carried out using RStudio and the Biblioshiny interface (Aria and Cuccurullo 2017). To reflect collaborative contributions fairly, species descriptions from multi-authored papers were equally attributed to all listed authors, regardless of authorship order. This approach acknowledges the collective nature of scientific discovery in taxonomy.

Results and discussion

New taxa described post-2000

Since 2000, there are obvious trends in the contribution to the description of Türkiye's freshwater fish species (Fig. 1A). A small group of researchers has made notable contributions individually, and collectively they account for most of the newly described species. This highlights the central role contributed by a few constantly active scientists to the advancement of the discipline. Nonetheless, the combined effort of numerous other scientists has also contributed hugely towards the expanded taxonomic knowledge of the country's freshwater fish fauna. These findings underscore both the concentrated expertise of a core group of specialists and the collaborative nature of broader scientific involvement in documenting Türkiye's ichthyofauna. Fig. 1B gives the freshwater fish species genus-wise distribution of species from Türkiye since 2000. *Oxynoemacheilus* has the highest number of represented species at 30 followed by *Salmo* Linnaeus, 1758 (17 species), *Cobitis* Linnaeus, 1758 (14 species), *Pseudophoxinus* Bleeker, 1860 (12 species), and *Alburnoides* (10 species). These genera are either firmly established in freshwater fish research from Türkiye or have intrinsically high richness. The notable diversity within *Cobitis*, *Salmo*, and *Oxynoemacheilus* exhibits the enormous ichthyological diversity of the country. On the other hand, nine freshwater fish genera from Türkiye were described or re-described since the year 2000: *Turcichondrostoma* Turan, Küçük, Güçlü & Aksu, 2021; *Egirdira* Freyhof, 2022; Chelon Artedi, 1793; *Planiliza* Whitley, 1945; *Salariopsis* Vecchioni, Arculeo, Hundt & Marrone, 2022; *Paracapoeta* Turan, Kaya, Aksu & Bektas, 2022; *Hemigrammocapoeta* Pellegrin, 1927; *Acanthalburnus* Berg, 1916; *Kosswigobarbus* Karaman, 1971. Among these, the new genus *Paracapoeta* has not been recognized as valid by Freyhof et al. (2025), and *Planiliza* was segregated from *Liza*. *Kosswigobarbus*, *Acanthalburnus*, *Liza*, and *Hemigrammocapoeta* were synonymized with *Carasobarbus*, *Acanthobrama*, *Chelon*, and *Garra*, respectively (Borkenhagen et al. 2011; Durand et al. 2012; Küçük et al. 2014; Behrens-Chapuis et al. 2015).

Most of the diversity and associated taxonomic issues of the Nemacheilidae family in Anatolia have been clarified by extensive numbers of scientific research conducted over the last decade (e.g., Freyhof et al. 2012, 2015, 2022; Esmaeili et al. 2014; Yoğurtçuoğlu et al. 2020; Kaya et al. 2024b). In this context, two genera stand out, namely *Oxynoemacheilus* and *Seminemacheilus*. The genus *Oxynoemacheilus* is the most species-rich in Türkiye; nevertheless, its taxonomy and nomenclature have long been obscured. Most of these issues were settled by recent integrative studies using morphological and molecular data (Freyhof et al. 2019; Bektaş et al. 2022; Yoğurtçuoğlu et al. 2022). As a result, between 2006 and 2024, 30 new species were described within the genus, significantly highlighting its diversity and importance (e.g., Freyhof et al. 2012, 2019, 2021, 2022; Kaya et al. 2020, 2021, 2024a). These findings show that *Oxynoemacheilus* plays an important role in local freshwater ecosystems and also point to the complexity of its taxonomy.

The endemic genus *Seminemacheilus* is also a clear example of recent progress in taxonomy. Although it was previously little known, the rediscovery of *Seminemacheilus lendlii* (Hankó, 1925) renewed scientific interest and led to further taxonomic clarification (Yoğurtçuoğlu et al. 2020). As a result, the genus is now recognized to include six valid species marking both a scientific advancement and a meaningful step toward conserving Anatolia's endemic fish genera.

The annual distribution of freshwater fish species identified in Türkiye since 2000 reveals notable fluctuations in discovery rates (Fig. 2). Between 2000 and 2005, the number of newly described species remained low. However, a sharp increase occurred in 2006, coinciding with strengthened scientific and institutional efforts to explore the country's aquatic biodiversity. After 2006, species discovery rates varied but peaked again in 2018. From that year onward, an average of 7.8 species were described annually, reflecting both methodological advancements in taxonomic research and enhanced international collaboration.

Between 2019 and 2024, a gradual decline in the number of newly described species was observed. This trend may suggest that much of Türkiye's freshwater fish biodiversity has been documented or that the remaining undiscovered species are taxonomically challenging and require more sophisticated techniques for their delimitation. In addition, the global COVID-19 pandemic likely impacted fieldwork and laboratory research during this period, contributing to the slowdown. The observed fluctuations in species discovery highlight the influence of local and global scientific efforts, methodological innovations, and funding availability. The recent decline underscores the importance of shifting focus toward conservation priorities and ecological research to better understand the roles and conservation needs of described species.

According to the data analyzed, the density of freshwater fish species described in Türkiye between 2000 and 2024 varies across regions. Given the geographical location of Türkiye at the intersection of three biodiversity hotspots, the Mediterranean and Irano-Anatolian regions are of particular interest (Fig. 3). A substantial portion of the species described within the Irano-Anatolian hotspot

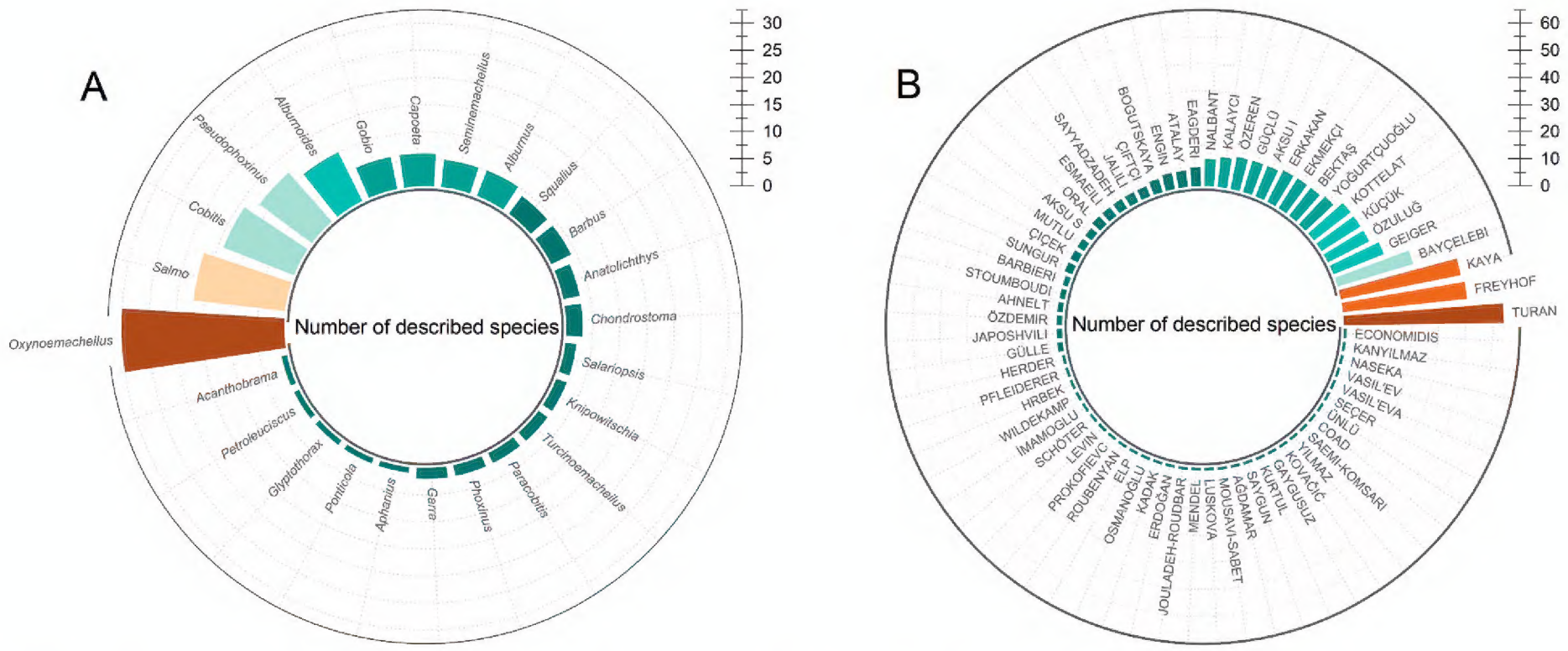

Figure 1. Number of described species according to authors (**A**) and genera (**B**).

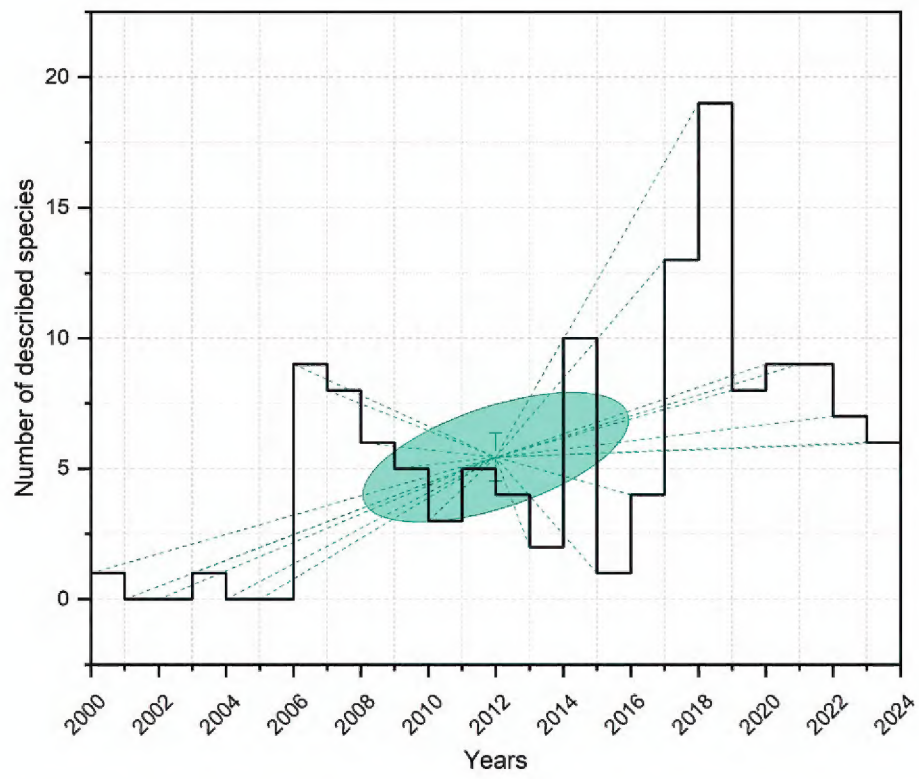

Figure 2. Annual distribution of the newly described freshwater fish species in Türkiye between 2000 and 2024. The center of the green zone represents the average number of described species with standard error. The green zone (ellipse) shows the direction of force.

during this period are also present in the Tigris and Euphrates rivers. Historically, the Tigris–Euphrates region – especially the Tigris – was underrepresented in scientific studies due to long-standing political instability and security concerns (Bayçelebi et al. 2024). However, more intensive fieldwork conducted in the 2010s revealed considerable species richness in this area (Kaya 2012; Kaya et al. 2016; Freyhof et al. 2017, 2018a, 2019). This increase in documented diversity is largely attributed to growing scientific interest and improved accessibility in recent years.

The Eastern Mediterranean region stands out as one of the richest areas in Türkiye in terms of freshwater fish diversity. This biodiversity is largely supported by its three major rivers: the Seyhan, Ceyhan, and Orontes (Bayçelebi 2020). In addition to their hydrological independence, these rivers are located at a biogeographic crossroads, receiving faunal influences from adjacent regions such as the Western Mediterranean (Kaya et al. 2019), Central Anatolia (Lakes Region, Kaya et al. 2025), the Black Sea basin (Freyhof et al. 2025), the Euphrates system (Kaya 2019), and possibly even from North Africa. These river systems exhibit particularly high diversity within the families Nemacheilidae (Kaya et al. 2020, 2021, 2025; Freyhof et al. 2021), Cobitidae (Freyhof et al. 2018b), and certain species of Leuciscidae (Saç et al. 2019a, 2019b; Küçük and Güçlü 2014; Bayçelebi 2020). The resolution of taxonomic uncertainties and the formal description of numerous species within these groups since the 2000s have significantly contributed to the high species richness recorded in the Eastern Mediterranean region (Fig. 3). In fact, not only the Eastern Mediterranean but also much of southern Anatolia – the Euphrates–Tigris basin, the Lakes Region, and western river systems such as those of the Aegean – is considerably more affluent in freshwater fish than the northern half of Türkiye. This is likely due to a combination of complex geological history, ecological heterogeneity, and the region's role as a biodiversity corridor and refugium.

Fig. 4 presents a brief overview of 60 type specimens (including holotypes and paratypes) linked to the 136 species covered in this study. This collection highlights the richness and diversity of Türkiye's freshwater fish fauna, as well as the importance of clearly documented type material in taxonomic work. By bringing these specimens together, we aim to show the value of type material in systematic research and its key role in addressing taxonomic uncertainties.

Availability of mitochondrial sequences and DNA barcoding

A total of 674 DNA barcode records representing 68 species were retrieved using the 'checklist' function in BOLD, based on the list of species in Suppl. material 2. Among these, the family Leuciscidae is the most represented, with 26 species, primarily from the genera *Pseudophoxinus* (11

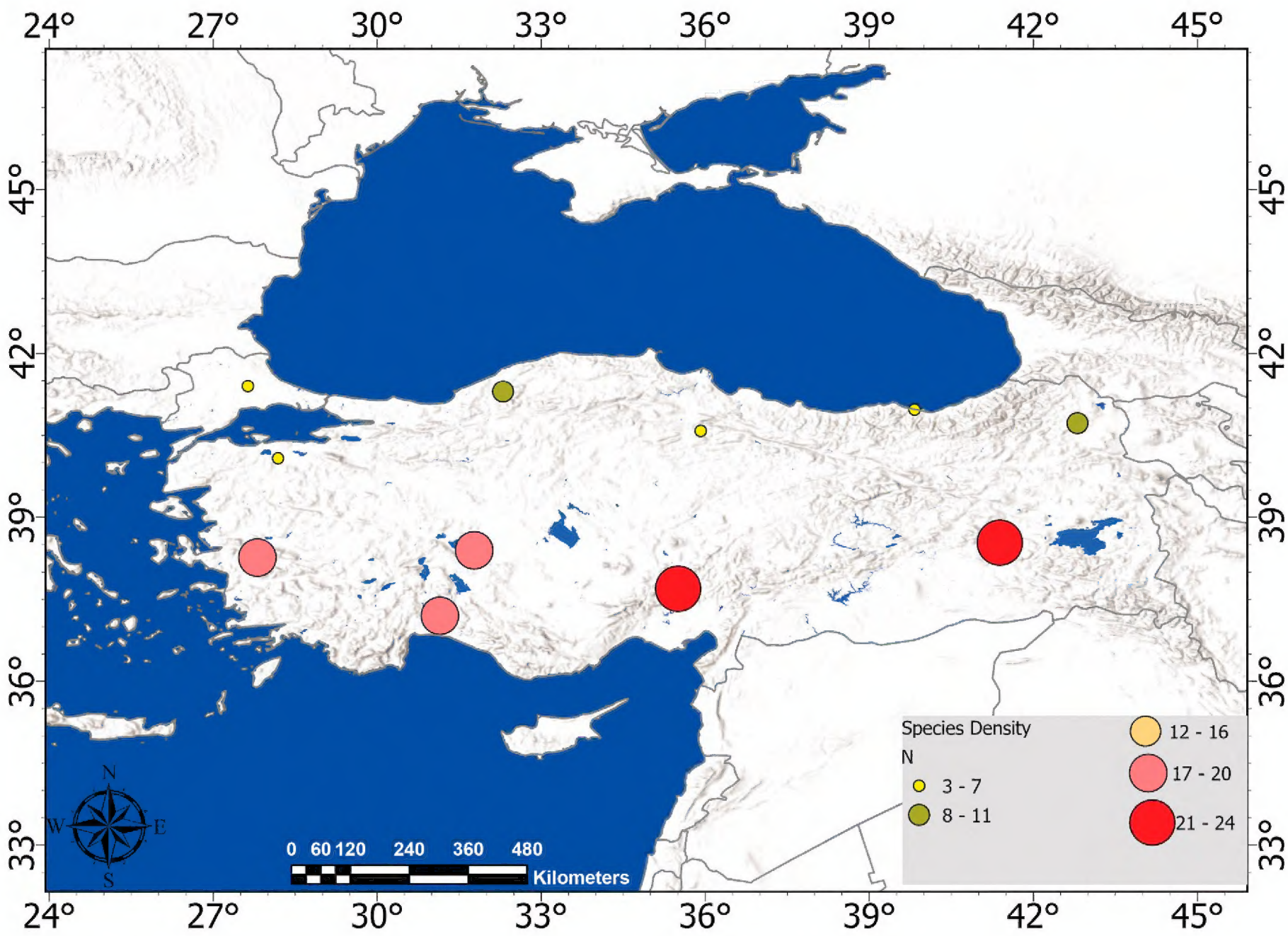

Figure 3. Number of newly described freshwater fish species by drainage basin in Türkiye.

Figure 4. Visual compilation of type specimens (holotypes and paratypes) of the 60 species documented in this study. Alphabetical identifiers and specimen details are provided in Suppl. material 1.

species) and *Alburnoides* (7 species). The second most represented family is Nemacheilidae, with 15 species, mainly from the genus *Oxynoemacheilus* (12 species). On average, 9.9 individuals are available per species, with a minimum of one individual recorded for three species – *Salmo euphrataeus*, *Pseudophoxinus turani*, and *P. iconii* – and a maximum of 55 individuals for *Cobitis saniae* (Suppl. material 2). Although these records are integrated into the BOLD search engine – facilitating the identification of unknown biological material from these species – only 421 records, corresponding to 53 species, are publicly available for download (Suppl. material 4). Most of the COI sequences originate from integrative taxonomic studies that aimed to resolve taxonomic uncertainties through a combination of molecular and morphological data. This is particularly true for genera that have been the focus of intensive research and fieldwork, such as *Oxynoemacheilus* (Yoğurtçuoğlu et al. 2022), *Alburnoides* (Turan et al. 2017a), and *Pseudophoxinus* (Bogutskaya et al. 2006; Freyhof and Ozuluğ 2010a, 2010b; Küçük and Güçlü 2014; Ekmekçi et al. 2015).

Among the DNA barcode records available for download, most species are represented by a single cohesive cluster of sequences and have been assigned a unique Barcode Index Number (BIN). Currently, 55 BINs are available for the 137 species described since 2000. Five BINs, however, occur in more than one species, which are instances of shallow mitochondrial divergence. These include BOLD:ADL8312 (*Alburnoides emineae* and *A. velioglui*), BOLD:ACL7151 (*Alburnus carianorum* and *A. demiri*), BOLD:ACB6151 (*Pseudophoxinus ninae* and *P. burduricus*), BOLD:AAB3872 (*Salmo opimus*, *S. labecula*, and *S. chilo*), and BOLD:AAE3493 (*Squalius aristotelis* and *S. orpheus*). These cases of shallow mitochondrial divergence observed at the species level are also seen in the distribution of K2P genetic distances. Specifically, eight species have larger maximum intraspecific K2P distances than minimum interspecific distances from the nearest relatives. They include *Alburnoides velioglui*, *A. carianorum*, *A. demiri*, *Gobio maeandricus*, *Oxynoemacheilus seyhanicola*, *Pseudophoxinus burduricus*, *P. ninae*, and *S. orpheus* (Suppl. material 3).

Bibliometric analysis of authors in the top ten

A bibliometric analysis was conducted focusing on the top ten researchers who have described the greatest number of fish species in the field. A general summary of the results is presented in Table 1. In total, 220 publications in 54 journals were considered. The annual growth rate of publications in this domain was calculated at 2.73%, reflecting a steady, albeit modest, increase in research output. Of most importance, work in this subcategory was discovered to be low prior to 2000, indicating that the literature foundation is relatively recent. This is further supported by an average document age of 7.5 years, although this figure may fluctuate depending on the evolving dynamics of the field. The average number of citations per publication was 12.8, suggesting a moderate level of visibility and impact in the scientific community. When the number of authors working in the field is considered, each author was cited 1.75 on average per publication, which is a very high number given the global trend in fish taxonomy where taxonomic work is less likely to be cited because it is specialized or not mainstream. Despite the specialty focus of fish species identification, such a high rate of citation testifies to the field's high impact and growing profile in the larger scientific community. The 220 papers collectively cited 5,240 references, the level of literature review as well as the rich knowledge base underpinning this research. Keyword analysis yielded 519 cited reference-derived distinctive keywords and 513 author-specified keywords, which indicates consistency of terms used within the field. 732 authors contributed to the body of work analyzed; however, only four documents were single-authored. The absence of individual efforts indicates the collaborative nature of fish taxonomy that often necessitates interdisciplinary input in genetics, morphology, and ecology. This can also be seen in the 7.17 average number of co-authors per publication, which indicates large-scale collaborations are the norm. In addition, 42.27% of the publications had international collaboration, highlighting Türkiye's extensive integration into global society for ichthyological research. Such high rates of cross-border co-authorship also reflect the enabling role of international collaborations to facilitate enhanced knowledge of Türkiye's freshwater fish biodiversity.

In journal rankings, Zootaxa leads the list with 50 publications, twice that of its closest rival, and is thus the primary journal for taxonomic studies in fish systematics (Fig. 5A). It also holds the highest citation count (436), owing mainly to its publication count (Fig. 5B). Other journals,

Table 1. Summary statistics of the bibliometric analysis of the authors (top ten) of new species of freshwater fishes described in Türkiye since 2000.

Description	Results
Main Information About Data	
Timespan	2000:2025
Sources (Journals)	54
Documents	220
Annual Growth Rate %	2.73
Document Average Age	7.52
Average Citations Per Doc	12.8
References	5240
Document Contents	
Keywords Plus (ID)	519
Author's Keywords (DE)	513
AUTHORS	
Authors	732
Authors of single-authored docs	4
Authors Collaboration	
Co-authors per Doc	7.17
International co-authorships %	42.27

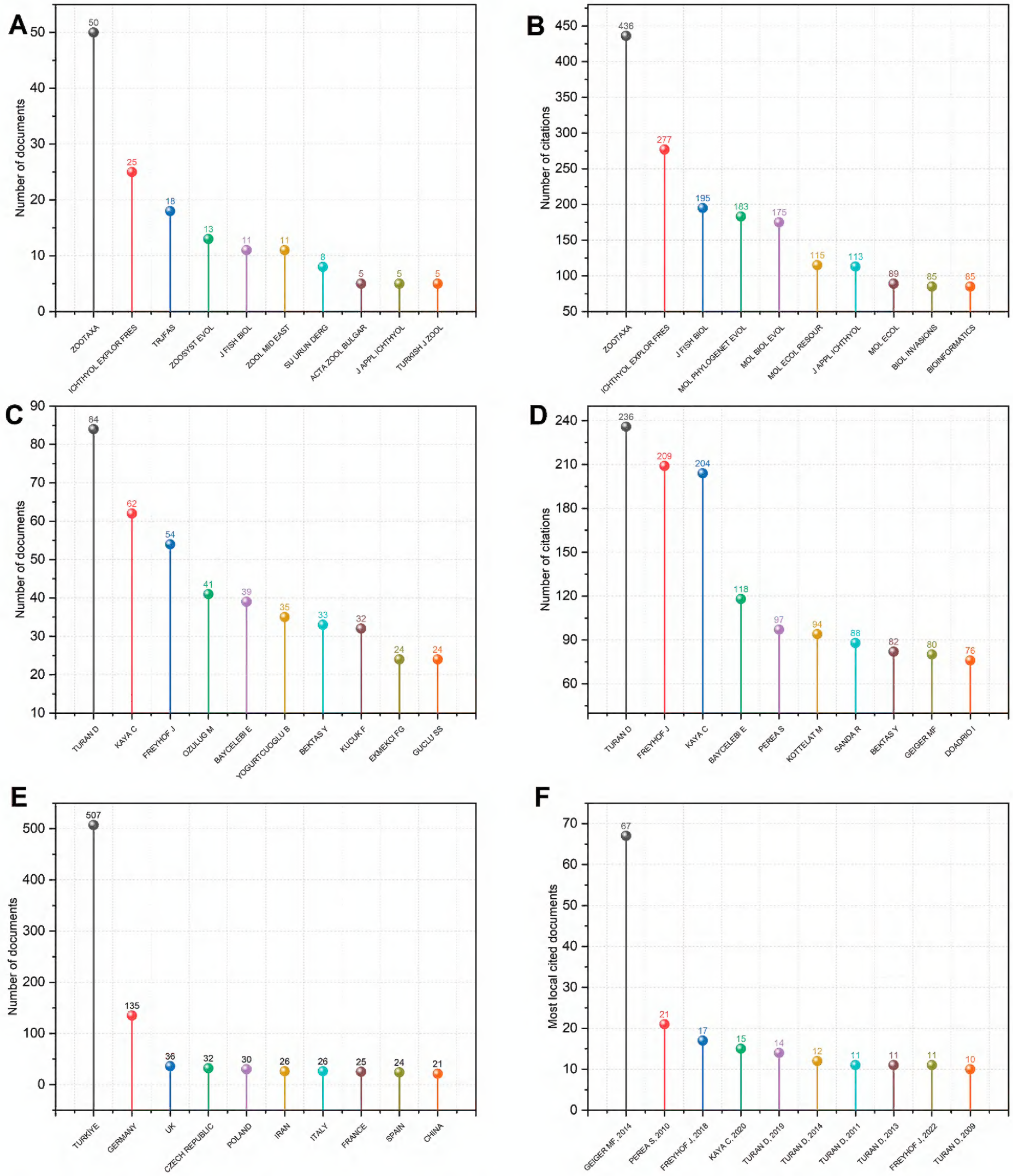

Figure 5. Publication summary of the top ten. **A.** Number of articles by journal; **B.** Number of citations by journals; **C.** Number of articles by authors; **D.** Number of citations by authors; **E.** Number of articles by countries; **F.** Number of citations by articles.

such as Journal of Fish Biology, Molecular Phylogenetics and Evolution, and Molecular Ecology Resources, have good citation performance with fewer articles, reflecting their high impact factors. The most prolific authors are Turan D. (84 articles), followed by Kaya C. (62) and Freyhof J. (54) (Fig. 5C). While Turan has the highest citation count, Freyhof's significant citation impact from fewer publications highlights the influence of his research (Fig. 5D). This suggests that few researchers significantly guide the area. Geographically, the majority of publications are come from Türkiye, followed by Germany, the UK, and other European countries (Fig. 5E), suggesting excellent international collaboration. The most cited paper, Geiger et al. (2014), received 67 citations, far exceeding most others (Fig. 5F). This highlights how a small number of studies generate most of the field's scientific impact.

The number of publications on freshwater fish taxonomy in Türkiye has steadily increased, especially after

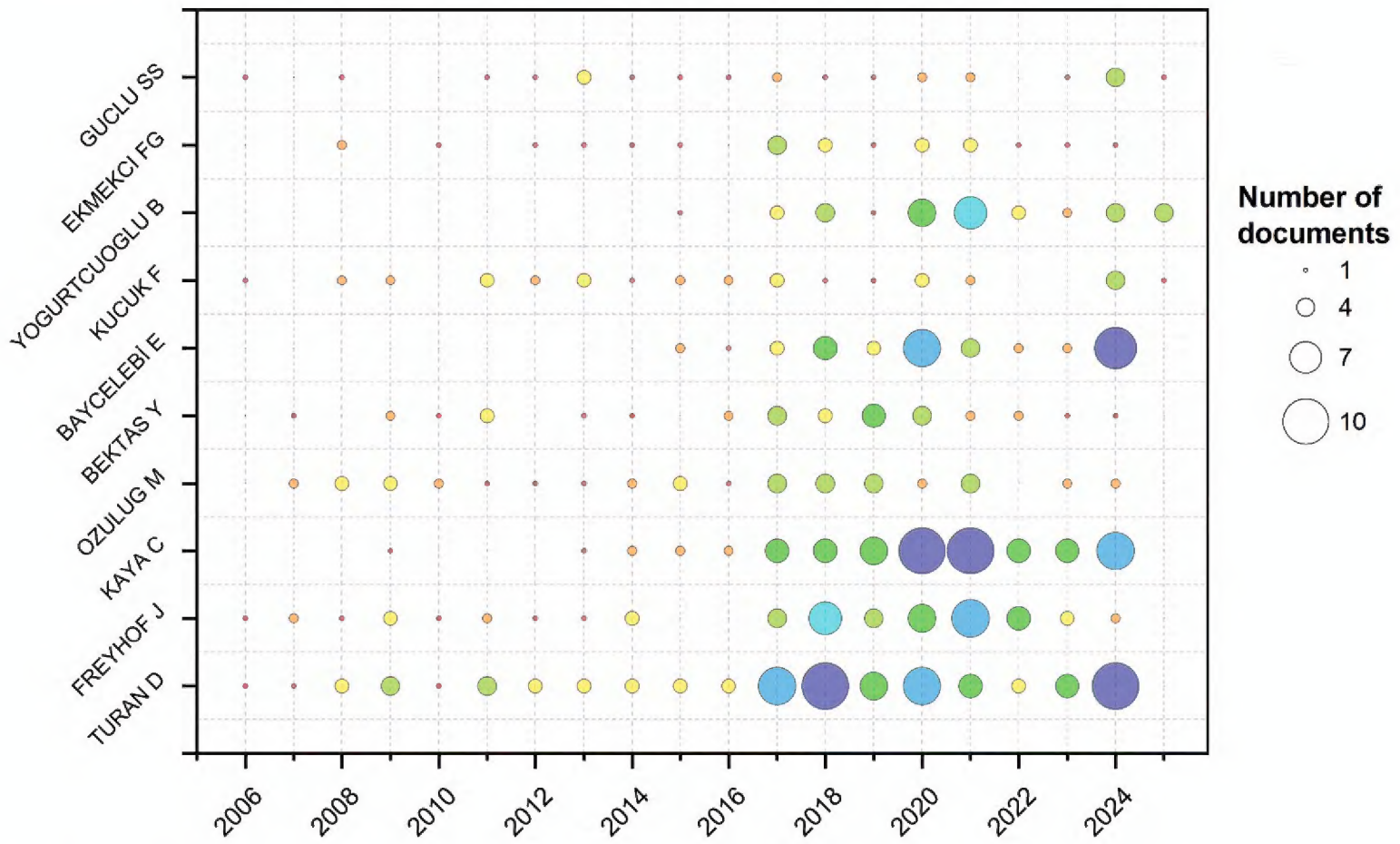

Figure 6. Number of studies published annually since 2006 by the top authors based on keyword analysis.

2016, with a noticeable peak between 2018 and 2024 (Fig. 6). Between 2006 and 2014, research activity was limited and irregular, but things picked up significantly after 2016 – likely due to advances in taxonomic methods, genetic tools, and growing international collaboration. Among the top scientists, Turan D. regularly published at an increased rate since 2018, cementing his prominence. Freyhof J. and Kaya C. also regularly and enormously published, whereas others such as Özuluğ M., Bektaş Y., and Bayçelebi E. maintained regular but smaller publishing numbers. The appearance of large collaborative groups in recent years reflects the trend of the field towards broader, inter-disciplinary collaborations, aided by increased funding and institutional resources. This points towards the growing expansion of the subject and its more global involvement within international ichthyology research.

Fig. 7A shows the most frequent keywords among publications employed in the current research. More extensive and heavier terms indicate higher frequency, hence also charting the thematic priorities of the field. Notably, terms such as "RIVER," "TURKEY," "ANATOLIA," "FRESHWATER FISHES," "BASIN," and "CYPRINIDAE" dominate the cloud, in that it indicates that the majority of studies are geographically concentrated on river basins in Türkiye, namely Anatolia, and taxonomically on family Cyprinidae.Additionally, the frequent use of words like "phylogeny," "biodiversity," "accuracy," "identification," and "growth" suggests that the studies are not limited to species description but also cover evolutionary and conservation biology themes. Fig. 7B illustrates the co-authorship network among researchers. The largest nodes (e.g., TURAN D. and KAYA C.) represent the most prolific authors with extensive collaborative ties. The network shows that productivity in the field of fish taxonomy in Türkiye is concentrated among a few major research groups. Connections with both domestic and international researchers (e.g., FREYHOF J., BAYCELEBI E., OZULUG M., GEIGER F.M.) are evident, demonstrating active international collaborations. Institutional interaction is exhibited in Fig. 7C by affiliation. Recep Tayyip Erdoğan University is at the center of the network, demonstrating its central role in fish species description and taxonomic research in Türkiye. The university is affiliated with several national and international institutions, as can be seen from its leadership in the field. Other notable institutions include Hacettepe University, Ege University, and Süleyman Demirel University, among others. Finally, Fig. 7D is the international cooperation map by country. Türkiye is at the center, with particularly strong ties to Germany, likely reflecting intense collaboration with scientists such as Freyhof J. Relations with other countries appear more dispersed and moderate, normally reflecting European and regional research focus.

It must be mentioned that a few new species described in Türkiye were first described from materials collected outside of Türkiye and later only documented from Türkiye by Turkish researchers. For instance, *Alburnoides petrubanarescui* Bogutskaya & Coad, 2009, *Alburnus atropatenae* Berg, 1925, and *Oxynoemacheilus elsae* Eagderi, Jalili & Çiçek, 2018, all described from Iran, were afterwards listed as new discoveries for Türkiye by Kaya (2020). Similarly, *Aphanius almiriensis* Kottelat, Barbieri & Stoumboudi, 2007, and *Oxynoemacheilus theophilii* Stoumboudi, Kottelat & Barbieri, 2006, first reported from Greece, were later found to exist in Anatolia (İnnal et al. 2015; Ağdamar et al. 2024). It should not be forgotten that species with such histories in Türkiye, have slightly increased the number of foreign researchers and foreign countries mentioned in this study.

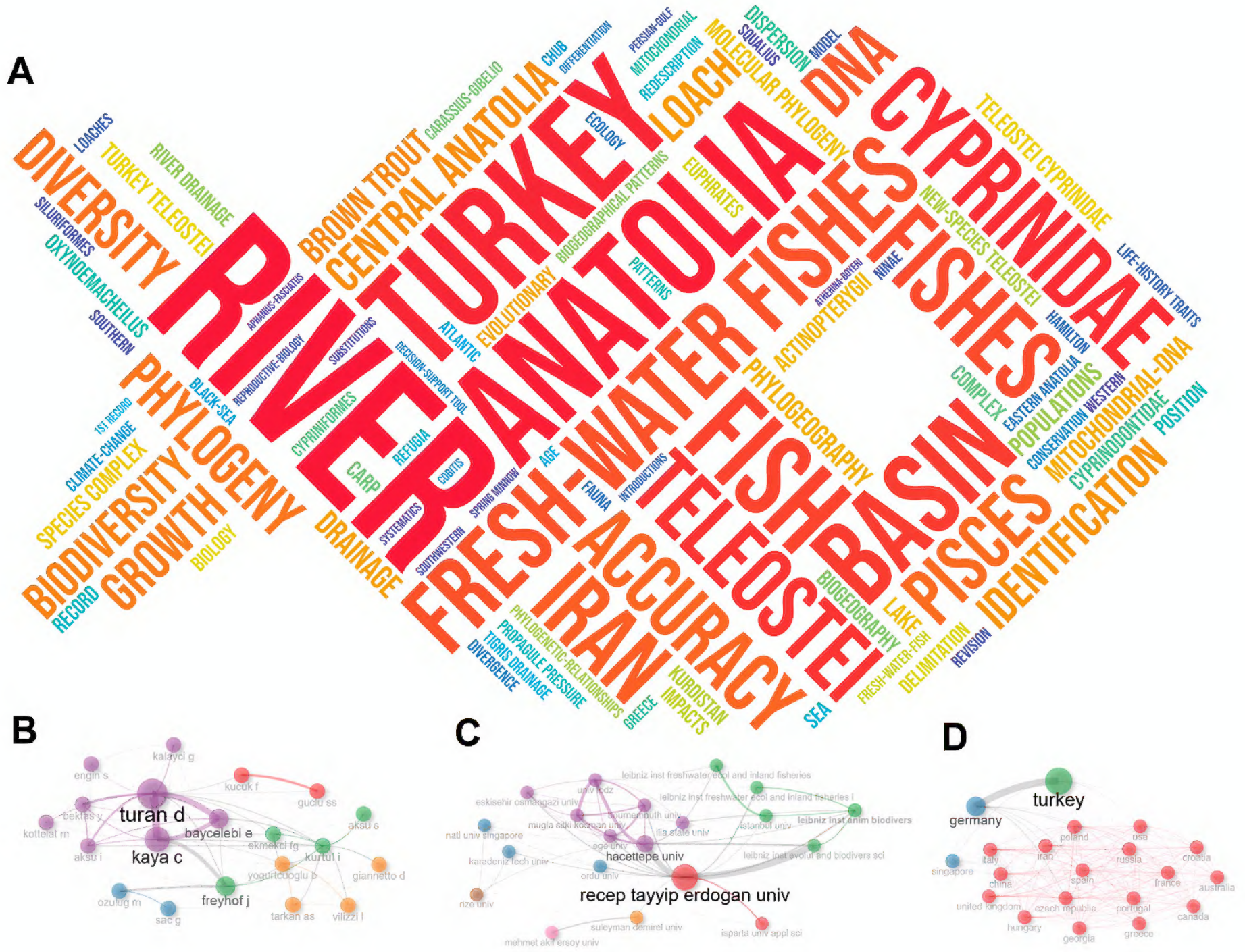

Figure 7. Trend topics and scientific networks. **A.** World cloud; **B.** Scientific networks between authors; **C.** Scientific networks between institutions; **D.** Scientific networks between countries.

The thematic map positions research themes according to their degree of development and significance within the field. The X-axis indicates the degree of relevance, or how much a theme is at the heart of the field, and the Y-axis indicates the density, or the degree of development in the subject. Each quadrants represents a different type of thematic cluster (Fig. 8A). The motor group themes include freshwater fish, species, and adaptation that identify that these are overarching themes in the field of study. They are dominant themes identifying the field and will continue to influence subsequent studies. Marine fish and trophic level are descriptive terms for study (niche subjects) that, while appropriate, do not have broad applicability to other fields of study. Terms such as "mitochondrial DNA" and "decision support tools" reflect that there are common themes at the core methodologies and ideas frequently used within a variety of research lines. The term "water recovery" suggests a potential emerging theme linked to environmental sustainability.

Factorial analysis reveals co-occurrence of research terms with different colored groups suggesting various thematic categories (Fig. 8B). The purple cluster (Taxonomy and Genetics) includes terms like "species", "genetic", "phylogenetics", and "evolution", which represent molecular and evolutionary views in taxonomy research. The green cluster relates to species identification and ecological studies, with frequent references to molecular tools used in identifying species and understanding their ecological roles. The red cluster is centred on phylogenetics and biogeography, emphasizing evolutionary relationships and the spatial distribution of species. In contrast, the blue cluster reflects a growing emphasis on genomic methods and conservation efforts, pointing to the integration of genome-scale data in taxonomic and biodiversity research.

Study limitations

This study focuses exclusively on freshwater fish species formally described within Türkiye, which may introduce a degree of limitation to the findings. Türkiye's strategic biogeographical position and high aquatic biodiversity have attracted considerable interest from both local and international researchers. Nevertheless, by restricting the scope to species described within national boundaries, the study may not fully reflect broader regional taxonomic patterns or the distribution of species that extend across borders.

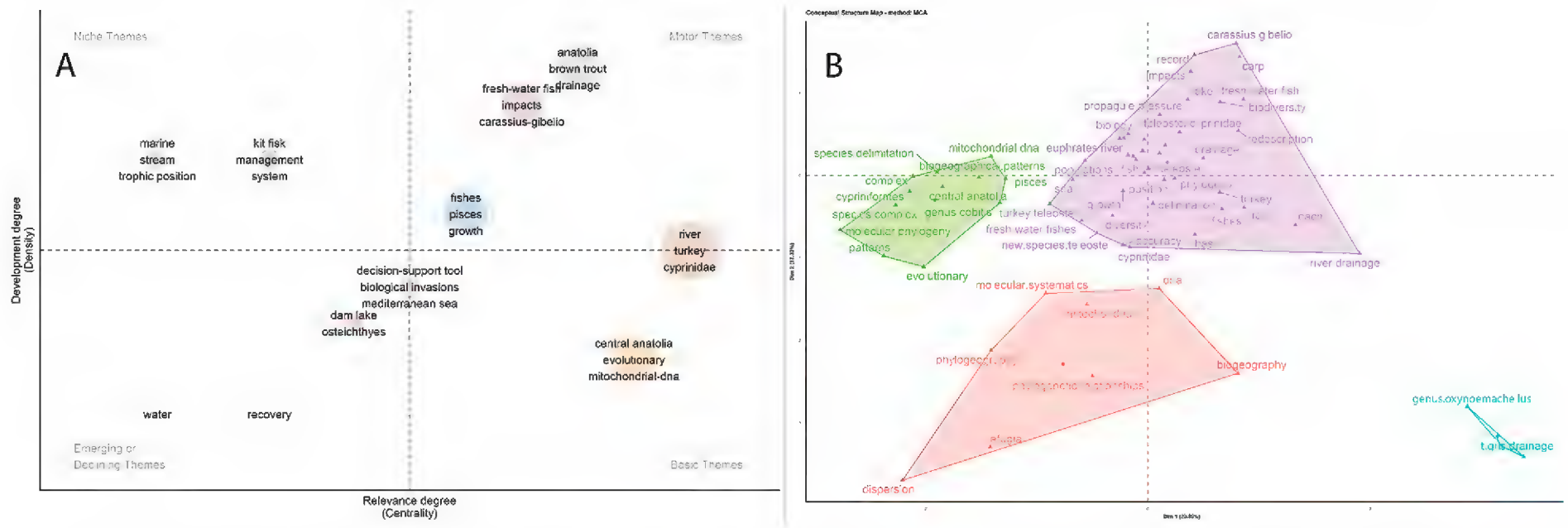

Figure 8. Advanced keywords analysis belonging to the field. **A.** Thematic map; **B.** Factorial analysis. Upper-Right Quadrant (Motor Themes): These are well-developed and highly relevant themes driving research in the field. Upper-Left Quadrant (Niche Themes): These are highly specialized but less central themes that may be of limited general interest. Lower-Right Quadrant (Basic Themes): These are fundamental topics with broad relevance but lower development. Lower-Left Quadrant (Emerging or Declining Themes): These topics have low density and low relevance, meaning they could either be newly emerging research areas or declining in interest.

Another limitation of the bibliometric analysis is its reliance exclusively on data retrieved from the Web of Science Core Collection. While this database is one of the most prestigious and widely used academic resources – particularly due to its SCI-E coverage, which ensures access to high-quality datasets – it does not encompass all publications available in other databases, both local and international. Consequently, some regionally important studies may have been excluded from the analysis.

In addition, this bibliometric analysis only focuses on the top ten scientists who have documented the newest fish species in the aquatic systems of Türkiye. While this approach may seem restrictive, the primary objective of the study is to present an overview of the post-2000 distribution of newly described species. By looking at the most productive and influential taxonomists in this field, the study provides a well-documented and representative overview of the scientific advancement in freshwater fish taxonomy in Türkiye.

Conclusion

This study highlights the pioneering role of Türkiye in freshwater fish taxonomy by focusing on species described in the post-2000 period. The study demonstrates that Türkiye's research on fish species discovery and richness of the ecosystem is significant in the global arena. Researchers from regional and international cooperation have been at the center of advancing knowledge in this area. Nationwide, Türkiye is the largest contributor and is accountable for nearly 65% of all newly described species. Germany and Russia follow as the top contributing nations, and foreign contributions are particularly dominated by researchers from these two countries. However, Turkish researchers continue to be at the center of this scientific development. A year-by-year comparison indicates a drastic increase in the species description in 2018, which indicates an increase in scientific work and a major research boom during that period. Alternatively, the precipitous decline in species descriptions post-2020 indicates that scientific output in this field is subject to annual fluctuations.

This study also includes a bibliometric presentation of the top ten most prolific scientists, demonstrating their contribution to taxonomy within Türkiye's freshwater fish. The findings indicate that relatively few scientists – most notably Turan D., Kaya C., and Freyhof J. – have played a crucial role in establishing the field. The percentage of higher-than-average international cooperation (42.27%) also indicates Türkiye's extensive incorporation into global ichthyological research networks. One well-documented limitation of the study is its exclusive reliance on the Web of Science Core Collection, which might have resulted in missing relevant local and international publications listed in other databases. Nevertheless, the bibliometric analysis is a helpful and representative overview of post-2000 trends in research, key contributors, and shifting methodologies that have continued to drive species discovery.

This study suggests that while the Türkiye inland fish fauna diversity is well established, much additional research must be done to clarify taxonomic uncertainties, especially within families such as Nemacheilidae, Cobitidae, and Leuciscidae. Species inhabiting small isolated water bodies or localized systems, such as those found in the less-studied regions or Turkish cave systems, are highly specialized, with adaptations suitable for limited and isolated environments, and are consequently highly vulnerable. Additionally, and more extensive, exploration of these faunal components will be required not only to guide effective action to conserve local biomes and sustain overall biodiversity but also to resolve taxonomic enigmas. To this end, the development and application of novel molecular techniques will provide invaluable contributions towards filling long-standing taxonomic enigmas in Türkiye's freshwater ichthyofauna.

Declarations

Conflicts of interest: The authors declare no relevant financial or non-financial interests.

Ethical approval: Ethics approval was not required for this study, as it is a review article and does not involve direct research on human or animal subjects.

Data availability: All datasets used during the current study are available from the corresponding author upon reasonable request.

Funding: This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Acknowledgments

We thank TÜBİTAK BIDEB (2219 Program) for supporting Cüneyt Kaya through a one-year postdoctoral scholarship for research conducted in the Czech Republic at Charles University, Prague. We gratefully acknowledge support for Irmak Kurtul provided by a Marie Skłodowska-Curie Postdoctoral Fellowship under the Horizon Europe program HORIZON-MSCA-2023-PF-01 (UKRI Grant Ref: EP/Z003237/1), funded by UK Research and Innovation (UKRI). Special thanks are extended to Sadi Aksu for his valuable assistance in illustrating the map. We thank TÜBİTAK BIDEB (2219 Program) for supporting Cüneyt Kaya through a one-year postdoctoral scholarship for research conducted in the Czech Republic at Charles University, Prague.

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Supplementary material 1

Checklist

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Data type: xlsx

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Supplementary material 2

BIN Discordance Report

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Data type: xlsx

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Supplementary material 3

Barcode Gap Analysis

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Data type: xlsx

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Supplementary material 4

BOLD TaxonID Tree

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